Geomorphic and physicochemical Features of floodplain Waterbodies of the lower Hunter Valley, N.S.W.

B. V. Timms

Timms, B. V. Geomorphic and physicochemical features of floodplain waterbodies of the lower Hunter Valley, N.S.W. *Proc. Linn. Soc. N.S.W.* 109(4), (1986) 1987: 311-324.

The lower ends of 42 tributary valleys of the lower Hunter and Paterson Rivers contain floodplain lakes because the tributary outlet has been blocked by alluvial deposits of the main stream. On average these waterbodies are elongated to dendritic in shape, 4.3ha in area, 2m deep and have a Shoreline Development index of 2.13. Typically they fill from local run-off and subsequently their levels are largely determined by fluctuations in the water table.

In the 5 waterbodies studied in detail, mean values for Total Dissolved Solids varied between 215 and 468mg l^{-1}, pH between 7 and 8, turbidity between 26 and 318 FTU's, Secchi disc depth between 30 and 100cm, and nitrates were *c.* 1.4mg l^{-1} and phosphates *c.* 0.4mg l^{-1}. These parameters fluctuated widely as the waterbodies filled and dried according to variable rainfall and evaporation. Water temperatures ranged from 12-32°C with no persistent stratification. Waters were of the sodium chlorocarbonate or sodium chloride types.

Almost all waterbodies are adversely affected by man, mainly via drainage, nutrient accessions and cattle usage.

B. V. Timms, Sciences Department, Avondale C.A.E., P.O. Box 19, Cooranbong, Australia 2265;
manuscript received 11 November 1986, accepted for publication 22 April 1987.

Key words: floodplain lakes, morphometry, water chemistry, turbidity, nutrients, water temperatures, conservation.

Introduction

Floodplains typically contain areas of ponded water. Such wetlands encompass a wide range in sizes, depths, geomorphic origins, degree of permanence, physicochemical features and aquatic macrophyte communities, so that even reconnaissance classification is difficult (e.g. see Cowardin *et al.*, 1979, for USA and Riley *et al.*, 1984, for NSW). Detailed and long term data sets are needed for each perceived type before such schemes can be much improved. A contribution towards this is made here for a small area of the Hunter Valley in which wetlands are genetically similar.

According to most textbooks, ponded water on floodplains typically lies in oxbow lakes (i.e. cut-off meanders) and in broad depressions (swamps) behind levees. These certainly occur on the Hunter floodplain from about Maitland downstream and on the floodplain of the lower Paterson River (Pressey, 1981). However in the section of the Hunter R. between Singleton and Maitland and also adjacent to the Paterson R. near Paterson, most ponded waters lie in depressions where small tributaries meet the main valley. These form when the main stream 'by deposition of levees and of sediment elsewhere on its flood bed, aggrades its course faster than aggradation can occur in lateral tributary valleys' (Hutchinson, 1957: 115). Hence streams in side valleys tend to become obstructed and water accumulates so they become partly drowned. In many cases the main river, when in flood, flows into the lateral valley and so lengthens the obstruction by reverse delta formation. Hutchinson (1957) uses the term 'lateral lakes' for these waterbodies, but this is unfortunate as it implies relationships to floodplain processes such as lateral migration. The more appropriate term of 'blocked valley lake' (Blake and Ollier, 1971) is used here.

All of the present waterbodies are wetlands in the broad sense (Cowardin *et al.*, 1979) but called 'lagoons' in the local vernacular. Overseas this term is usually used genetically for coastal marine waterbodies, but in Australia it generally refers to shallow, often small, inland waterbodies in any geomorphic situation. This general descriptor is appropriate here though technically those lacking emergent macrophytes are lakes or ponds according to size and depth and those covered with emergent macrophytes are swamps (Bayly and Williams, 1973; Riley *et al.*, 1984). A few lagoons in downstream parts of the study area were included by Pressey (1981) in his inventory, but otherwise little is known of those investigated here.

Methods

Locations of possible lagoons were ascertained from 1:25,000 topographical maps and aerial photographs and checked first from a light plane and then on the ground. The depth (when full) and siting with respect to local geology and landforms were ascertained in the field for each lagoon. The area and shore length of all except the smallest/shallowest lagoons were determined in the laboratory by planimetry and measurement from enlarged vertical aerial photographs.

Three lagoons, 'Birds' (4), 'Bootlands' (19) and 'Murphys' (21) were sounded at 5m intervals along numerous lines (30, 42 and 26 lines respectively in each lake) stretched between known places on opposite shores. From the resultant bathymetric maps, direct and derived parameters were determined using formulae given in Bayly and Williams (1973) and Hakanson (1981). Altitudes were estimated to $\pm$2m from topographic maps.

Five representative lagoons in the Gosforth series with a wide range in size and degree of permanence were chosen for a study of the physicochemical features of the waters of the 42 floodplain lagoons. A causeway separated 'Bootlands' (19) into two parts on almost all visits, so both parts were sampled separately. Visits were made at monthly intervals for 63 consecutive months commencing in October 1979 and information was collected on water depth, temperature (by a resistance thermometer), light penetration (by a standard 20cm Secchi disc), pH (by a Selbys 800 pH Meter), Total Dissolved Solids (by gravimetry), and on turbidity, phosphate and nitrate (determined on a HACH Environmental Laboratory DR/EL 1). Samples were always taken in the morning between 0800 and 1200hrs and in the same sequence (Lagoons 19 to 23). From water samples collected in February 1981 the major ions were measured — Na and K by flame photometry, Ca and Mg by titration with EDTA, Cl by titration against $AgNO_3$, HCO_3 by titration with 0.01N HCl to an end point of pH 4.5, and SO_4 by the turbidimetric $BaSO_4$ method (Anon, 1975). Accuracy for all physicochemical methods was $\pm$2.5% or better.

Where possible, landowners of each lagoon were interviewed in an attempt to establish the influence of river floods, local heavy rain and droughts on water level fluctuations. Their opinion of the lagoons (e.g. water resource value, nuisance value) and the extent of their (or their predecessor's) modifications, if any, of the lagoons was also canvassed.

Results

(a) Geomorphology

Of the 42 floodplain lagoons in the study area, 31 occur along the Hunter R. and 11 along the Paterson R., giving densities of 0.7km and 1.2km respectively. The lagoons

TABLE 1

Summary of information on 42 floodplain lakes of the Hunter and Paterson Rivers

LAKE	MAP REFERENCE	AREA* (ha)	DEPTH* (m)	PERIMETER LENGTH* (m)	SHORELINE DEVELOP-MENT*	PERMANENCE +	MODIFICATIONS
Dalwood Series							
1. Unnamed	Elderslie 9132-I-N 498902	0.9	?	—	—	semipermanently flooded	none
2. Unnamed	Elderslie 9132-I-N 501903	1.2	3.2	—	—	semipermanently flooded	none
Luskintyre Series							
3. Unnamed	Greta 9132-I-S 503854	<0.5	—	—	—	seasonally flooded	none
4. 'Birds'	Greta 9132-I-S 514854	6.8	2.5	2350	2.55	permanently flooded	partly drained
5. 'Peters'	Greta 9132-I-S 506851	0.7	?	590	2.02	seasonally flooded	none
6. 'Russells'	Greta 9132-I-S 507842	7.1	2.1	2510	2.66	intermittently exposed	partly drained
7. Unnamed	Greta 9132-I-S 508829	<0.5	—	—	—	seasonally flooded	none
8. 'Martins'	Greta 9132-I-S 523823	4.7	2.6	1870	2.44	intermittently exposed	partly drained
9. Windermere	Greta 9132-I-S 538834	1.7	—	—	—	seasonally flooded	drained
10. Unnamed	Greta 9132-I-S 532840	<0.5	—	—	—	seasonally flooded	drained
11. Kaludah	Greta 9132-I-S 531813	10.3	?	2310	2.03	seasonally flooded	drained
12. 'Appledene'	Greta 9132-I-S 530835	1.5	—	—	—	seasonally flooded	drained
13. 'Windella 1'	Greta 9132-I-S 546851	0.8	—	—	—	seasonally flooded	none
14. 'Windella 2'	Greta 9132-I-S 551851	0.9	—	—	—	seasonally flooded	none
Rosebrook Series							
15. 'Rosebrook Sch'	Maitland 9232-IV-S 603860	5.9	2.2	1800	2.08	semipermanently flooded	partly drained
16. 'Rosebrook Sth'	Maitland 9232-IV-S 606841	1.1	?	590	1.56	seasonally flooded	drained
17. 'Dickensens Rd. big'	Maitland 9232-IV-S 617828	4.7	1.8	1690	2.19	semipermanently flooded	drained
18. 'Dickensens Rd. small'	Maitland 9232-IV-S 621831	1.3	?	760	1.88	seasonally flooded	drained
Gosforth Series							
19. 'Bootlands'	Greta 9132-I-S 584868	8.0	3.9	2890	2.87	permanently flooded	none
20. 'Burgess'	Greta 9132-I-S 591862	1.2	1.9	626	1.65	semipermanently flooded	partly drained
21. 'Murphys'	Greta 9132-I-S 592851	7.4	2.4	2170	2.20	intermittently flooded	partly drained
22. Unnamed	Maitland 9132-IV-S 597845	2.4	1.8	900	1.63	semipermanently flooded	partly drained
23. Unnamed	Maitland 9132-IV-S 598843	0.6	?	380	1.32	semipermanently flooded	partly drained
24. 'Birds' Folly'	Greta 9132-I-S 593827	11.0	—	2610	2.22	semipermanently flooded	drained
25. 'Greens'	Greta 9132-I-S 591821	10.7	1.5	2810	2.43	intermittently flooded	partly drained
26. Anambah	Maitland 9132-IV-S 602815	9.9	0.9	2660	2.25	seasonally flooded	drained

TABLE 1 (Continued)

LAKE	MAP REFERENCE	AREA* (ha)	DEPTH* (m)	PERIMETER LENGTH* (m)	SHORELINE DEVELOP-MENT*	PERMANENCE +	MODIFICATIONS
Oakhampton Series							
27. Oakhampton Swamp	Maitland 9132-IV-S 642803	*ca*26	—	—	—	intermittently flooded	partly drained
28. Walka Lagoon	Maitland 9132-IV-S 639793	*ca*20	7 ?	—	—	permanently flooded	damned
Bolwarra Series							
29. Unnamed Far Nth	Maitland 9132-IV-S 664808	2.3	—	920	1.70	seasonally flooded	drained
30. Unnamed Nth	Maitland 9132-IV-S 660797	2.5	—	—	—	semipermanently flooded	drained
31. Unnamed Sth	Maitland 9132-IV-S 659795	1.4	2.0 ?	—	—	intermittently flooded	
Paterson Series							
32. 'Tocal' Sth	Maitland 9132-IV-S 686878	1.9	4.0 ?	810	1.66	intermittently flooded	none
33. 'Tocal' Nth	Maitland 9132-IV-S 687888	0.7	1.5	—	—	intermittently flooded	partly drained
34. 'Tocal' Homestead	Paterson 9232-IV-N 678896	7.6	2.5 ?	2010	2.66	permanently flooded	none
35. 'Orange Grove'	Maitland 9132-IV-S 690884	0.7	—	—	—	semipermanently flooded	partly drained
36. 'Duninald' Sth	Paterson 9232-IV-N 687895	<0.5	—	—	—	semipermanently flooded	partly drained
37. 'Duninald' Nth	Paterson 9232-IV-N 690899	1.1	—	—	—	seasonally flooded	drained
38. 'Bona Vista'	Paterson 9232-IV-N 693907	6.4	2.5 ?	2970	3.30	semipermanently flooded	partly drained
39. Unnamed South of Paterson	Paterson 9232-IV-N 698913	3.7	—	—	—	semipermanently flooded	partly drained
40. Unnamed in Paterson	Paterson 9232-IV-N 701917	<0.5	—	—	—	semipermanently flooded	partly drained
41. 'Brisbane Grove'	Paterson 9232-IV-N 703924	1.3	—	—	—	semipermanently flooded	none
42. 'Valentia'	Paterson 9232-IV-N 696933	<0.5	—	—	—	seasonally flooded	none

* measured at full water level
\+ scheme according to Cowarden *et al.*, (1979)

range in size from <0.25ha to *c.* 26ha (Table 1), with the average being 4.3ha. However few approximate the average as size distribution is negatively skewed and somewhat bimodal. There is one peak in the 1.1–1.5ha class and another lesser one in the 5.1–7.5ha class (Fig. 2a). All lagoons stand many metres (*c.* 2-10) above the normal water level of the river. Limited data on maximum depths suggest the lagoons are relatively shallow, with the majority *c.* 2m deep and the deepest only 7m. The latter (No. 28), though, is artificially dammed so that the deepest natural lagoon is only 4m.

Shoreline Development (i.e. the ratio of the length of the shoreline to the length of the circumference of a circle of the same area) lies between 1.3 and 3.3, with an average of 2.13 for the 21 lagoons measured. This indicates these lagoons are either branched or have indented shorelines (see Figs 1,3 and 5). Actually the average for all 42 lagoons is probably a little less than 2.1, because the unmeasured lagoons generally had smoother shorelines than measured ones.

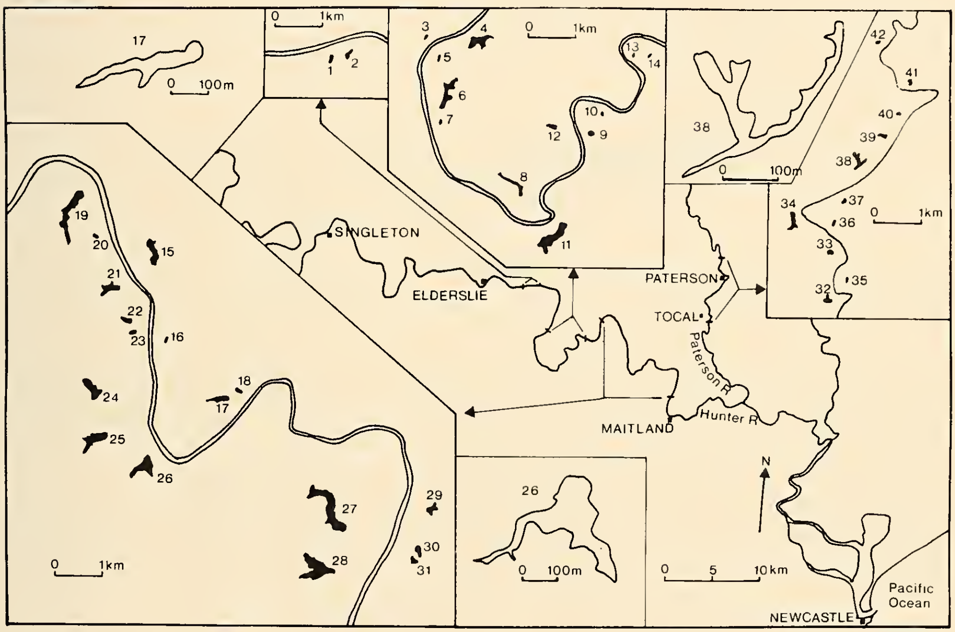

Fig. 1. Map showing location of the 42 lateral lakes studied in the lower Hunter. Three inserts give details of the shape of 3 quite different lagoons — No. 17, a lagoon in an essentially unbranched valley; No. 26, a lagoon in a branched valley and No. 38, a composite lagoon with one part a blocked valley lake and the other a lateral levee lake.

Water regimes vary widely but are accommodated within the four categories of the classification of Cowardin *et al.* (1979). Just four (9.5%) lagoons are *permanently flooded* and even two of these are artifically dammed. A natural example is No. 19 ('Bootlands') which contained water for all 63 months it was studied, even during the 1980 and 1983 droughts (Fig. 4). In a few lagoons (19%) the bottom is *intermittently exposed*, i.e. water is present except during extreme droughts. Examples are No. 21 ('Murphys') which only dried for 5 months during the 1980 drought (Fig. 4) and No. 25 ('Greens') which has dried 3 times during the last 26 years during the final stages of an extended drought (J. Green, personal communication). Many lagoons (35.7%) are *semi-permanently* flooded containing water for 1/3 to 2/3rds of the time. Lagoons 20, 22 and 23 are examples (Fig. 4). There are also many ephemeral lagoons (35.7%) that are *seasonally flooded* for <3 months in most years.

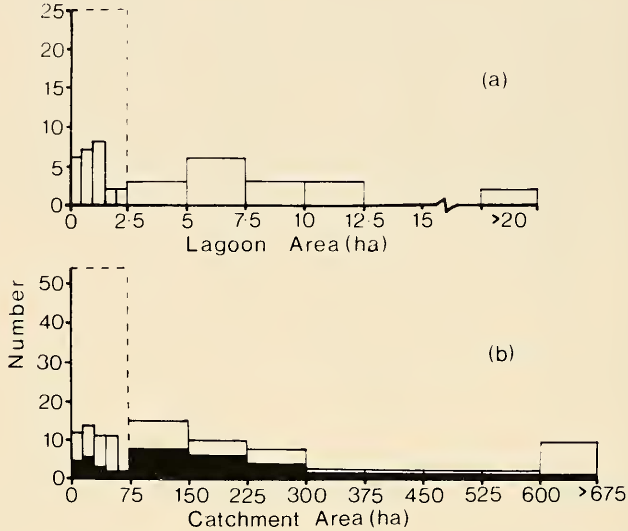

Fig. 2. Histogram showing the distribution of (a) lagoon sizes and (b) catchment sizes. In the latter case the proportion of catchments containing lagoons in each size class is indicated by the solid part of each block.

The relative number in each group of the above classification, especially in the semipermanently flooded and seasonaly flooded groups, has been influenced by drainage programs (Table 1) so that in the past more were in the intermittently exposed and permanently flooded classes. In fact most of the lagoons have been partly or completely drained, so that only a third have natural hydrological regimes.

The three lagoons that were mapped are similar morphometrically (Table 2, Fig. 3). 'Birds' Lagoon with its three distinct arms is the most branched, but 'Bootlands' has a higher S.D. because of its irregular shoreline. Volume development (i.e. ratio of the

TABLE 2

Morphometric Parameters of three lateral lakes of the lower Hunter River

Parameter	'Birds' L.	'Bootlands' L.	'Murphys' L.
Area (ha)	6.79	8.04	7.40
Volume ($m^3 \times 10^4$)	9.10	14.80	8.44
Max Depth (m)	2.5	3.9	2.4
Mean Depth (m)	1.34	1.84	1.14
Shoreline length (m)	2350	2890	2170
Shoreline Development	2.55	2.87	2.20
Volume Development	1.59	1.42	1.42
Length (m)	460	625	655
Width (m)	305	170	205
Altitude (m)	*ca*18	*ca*16	*ca*15

All measurements made at full lake level. See text and Bayly and Williams (1973) for explanation of the parameters Shoreline Development and Volume Development.

volume of a lake to that of a cone of basal area equal to the area of the lake and height equal to the maximum depth of the lake) in each is relatively high in keeping with the steep littoral area and flat floor. In 'Birds' (Fig. 3**a**) and 'Bootlands' the deepest point is well removed from the levee dam, but in 'Murphys' it is close by (Fig. 3**b**).

(b) PHYSICOCHEMICAL PARAMETERS

All physicochemical data refer to the five lagoons (19-23) in the Gosforth series which were studied over a 63-month period from October, 1979 to December, 1984. Rainfall (see Fig. 4) was well below average during 1980 and again in late 1982 — early 1983, so these were drought years. There were some periods of high rainfall (e.g. February 1981, March 1982, Fig. 4) which produced significant local run-off, but there were no river floods during 1979-84.

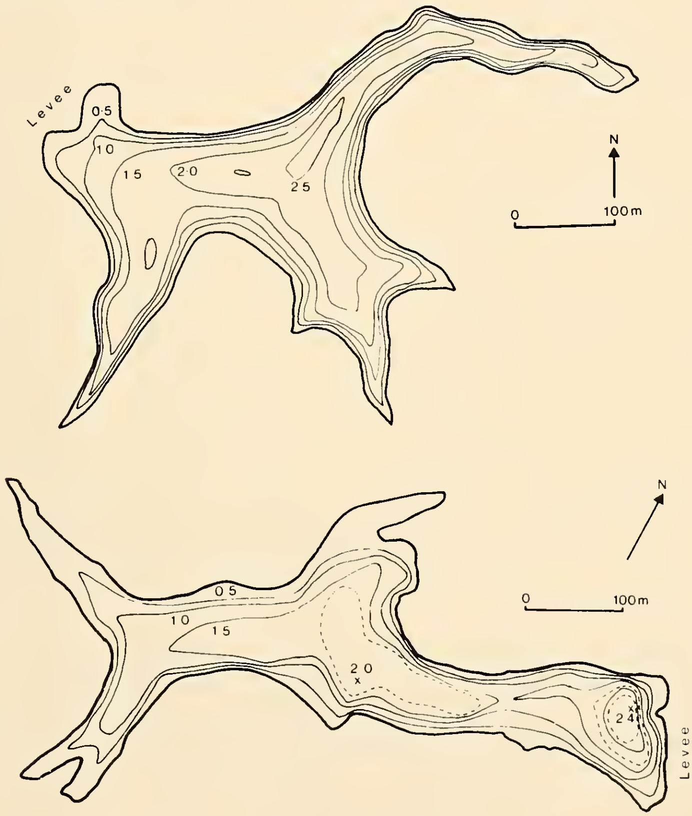

Fig. 3. Bathymetric map of **a** (above) Lagoon No. 4 'Birds' and **b** (below) Lagoon No. 21, 'Murphys'. Contours at 0.5m intervals, with some dashed ones at 0.25m intervals.

Mean TDS for the lagoons varied between 215 to 468mg l^{-1} (Table 3, Fig. 4). The lowest value recorded was 87mg l^{-1} in Lagoon 22 and the highest was 2208mg l^{-1} in Lagoon 21. During the two droughts there were steady increases in TDS to unusually high values, particularly in Lagoons 19b, 21, and 22. Fluctuations were a function of the relative input of run-off and loss by evaporation (Timms, 1970a) as expressed by the significant correlation between the ratio catchment area: lagoon surface area and annual

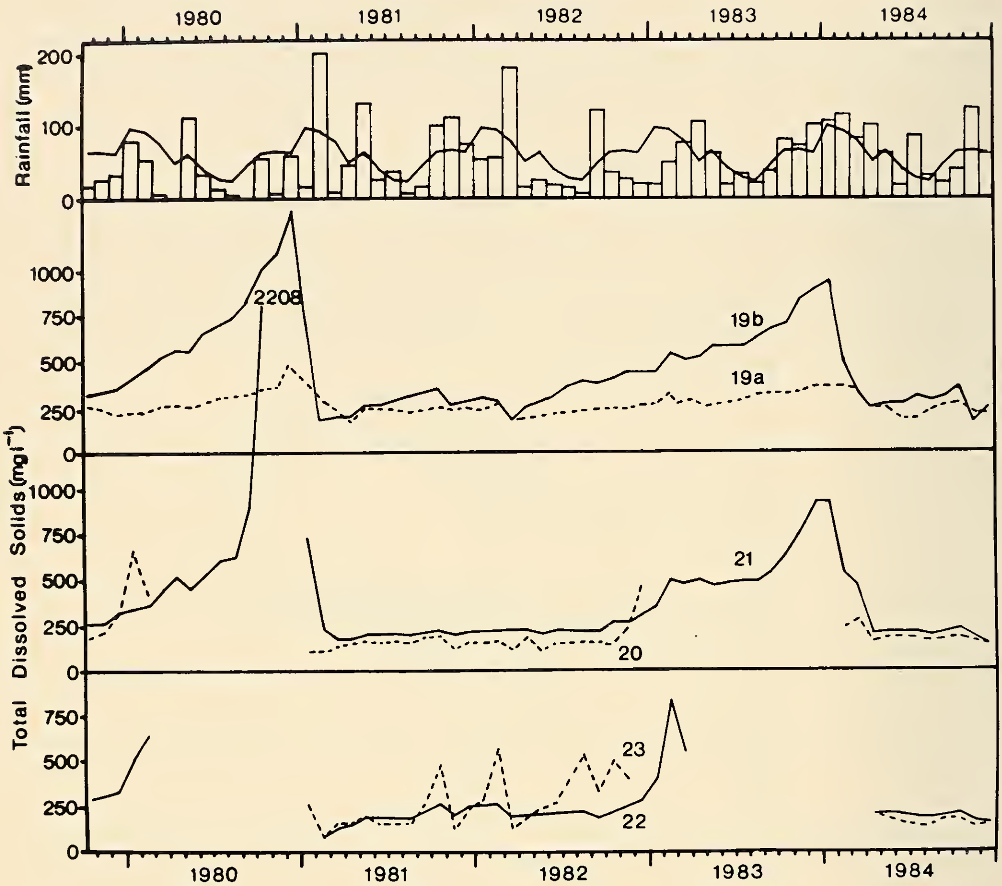

Fig. 4. Monthly rainfall (and long term average) at Singleton (nearest Meteorological Station) and TDS for lagoons 19-23 for period October 1979 to December 1984. Gaps in the TDS curves indicate the lagoons were dry for those periods.

percentage fluctuation in TDS ($r=0.8239$, $n=6$, $P<0.05$). Fluctuations in lagoon 19a were much less than in 19b, yet both are sequentially located in the same valley (Fig. 5) and joined during high water. This is explained in part, by lagoon 19b receiving proportionally more run-off than 19a, but it also has salty springs along its western shore (R. Bootland, personal communication).

Waters in the 5 Gosforth lagoons are of the sodium chlorobicarbonate type. Cationic dominances were $Na>Mg>Ca>K$ in all lakes, but anionic dominances varied between $HCO_3>Cl>SO_4$, $HCO_3=Cl>SO_4$ and $Cl>HCO_3>SO_4$ (Table 4). Generally all 5 lagoons were slightly alkaline with pH's between 7 and 8 (Table 4). No regular pattern of variation was evident. Unusually high pH values of 9.0-9.4 were seen in Lagoons 21 and 22 in low rainfall summers and equally unusual pH values of 6.2-6.8 were measured in Lagoons 19b, 20 and 23 after large inflows.

Water temperatures varied seasonally from late winter lows of *c.* 12-13°C to summer highs of *c.* 27-32°C (Table 3). The extreme range was 10.8°C in Lagoons 19a to 34.4°C in Lagoon 23. All values, especially the maxima, were influenced by the time of measurements. This explains the steady increase in values from 19 to 23, but even so

TABLE 3

Summary of some physicochemical parameters of lakes 19-23

Lake	TDS ($mg\ l^{-1}$)			pH		Temperature (°C)		Turbidity (FTU)		Secchi disc depth (m)		Nitrate ($mg\ l^{-1}$)		Phosphate ($mg\ l^{-1}$)	
	mean	SD	Fluctuation*	mean	SD	mean min	mean max	mean	SD	mean	SD	mean	SD	mean	SD
19a	265	61	90	7.7	0.9	12.2	26.9	52	30	0.63	0.41	1.2	0.8	0.47	0.33
19b	468	256	174	7.8	0.9	12.3	27.3	115	60	0.36	0.25	1.2	1.1	0.30	0.23
20	215	141	155	7.3	0.7	12.0	28.2	48	42	0.76	0.34	1.6	0.7	0.43	0.23
21	400	320	282	8.0	0.9	12.6	28.1	26	25	1.00	0.47	1.2	0.6	0.20	0.14
22	269	150	66	7.6	0.8	12.8	31.0	32	22	0.63	0.38	1.6	0.7	0.31	0.35
23	247	136	294	7.0	0.4	12.1	32.6	318	460	0.30	0.20	1.8	2.0	0.68	0.37

* These are mean figures for the 5 years (October 1979 to December 1984) and are calculated by dividing the difference between the greatest and lowest value each year by the lowest value and expressing as a percentage.

TABLE 4

Ionic composition of the water of lakes 19-23

Lake	Cations ($meq.\ l^{-1}$)				Total Ionic Conc.		Anions ($meq.\ l^{-1}$)		
	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cations	Anions	Cl^-	HCO_3^-	SO_4^{2-}
19	1.10	0.07	0.56	0.40	2.03	2.01	0.83	1.02	0.16
20	0.52	0.03	0.44	0.40	1.39	1.30	0.63	0.60	0.07
21	1.20	0.05	0.92	0.66	2.83	2.80	1.35	1.35	0.10
22	0.46	0.02	0.42	0.32	1.22	1.14	0.42	0.70	0.02
23	0.46	0.02	0.34	0.26	1.08	1.14	0.44	0.62	0.08

lagoons 20 and 23 tended to be warmer in summer and colder in winter because of their relative shallowness. During the summer months Lagoons 19a, and to a lesser extent 19b, 21 and 22, were often thermally stratified. In that bottom temperatures were only occasionally constant or slightly elevated from one month to the next, it is likely stratification rarely persisted between visits.

Turbidity also varied between and within the lagoons with mean values between 26 and 318 FTU's (Table 3) and extremes ranging from 0 in Lagoon 21 to 1600 in Lagoon 23. Values in Lagoon 23 were largely unnatural, as cattle trampled in it particularly during low water levels. The high values in Lagoon 19b may also be unnatural as European Carp, which are thought to muddy waters by their feeding activities (Tilzey, 1980), were present. There was little pattern in turbidity variations though, in general, values were highest following intense run-off. Algal blooms only had a noticeable effect in Lagoon 19a where *Oscillatoria* sp. regularly bloomed in late summer.

Light penetration, as measured by Secchi disc depth, varied from a mean value of 30cm to 100cm. The lowest recorded value was 1cm in Lagoon 23 and the highest 190cm in Lagoon 19a. Mean values in Lagoons 20, 21 and 23 should be a little higher as occasionally the disc reached the bottom before becoming obscured. Not surprisingly, turbidity and Secchi disc values were negatively correlated ($r = -0.7756$, $n = 6$, $P > 0.05$).

Nutrients in the 5 lagoons were of the same order of magnitude, averaging *c.* 1.4.mg l^{-1} NO_3-N and *c.* 0.4mg l^{-1} PO_4-P (Table 3). Lagoon 23 had the highest values and Lagoon 21 the lowest, with the former situation easily related to its use by cattle. Values in Lagoon 20 were probably elevated by intermittent agriculture and use of fertilizers in its catchment, and in Lagoon 19a the relatively high phosphates could be due to the 50-100 commercial ducks kept in a partially submerged pen on one bank. Nutrient values fluctuated erratically, but in lagoons which dried nutrients were elevated soon after filling and often during low water periods as well.

Discussion

(a) GEOMORPHOLOGY

Almost all of the lagoons studied fit the characteristics of the blocked valley lake type of Blake and Ollier (1971) (= lateral lake type of Hutchinson, 1957). Typically they are contained wholly or largely within small side valleys cut into Permian or Carboniferous sandstones, siltstones and mudstones or into high river terraces (e.g. No. 11) and with their lower ends blocked by natural levees of the Hunter or Paterson Rivers. Many, like Nos. 19 and 21 (Fig. 5) end abruptly at the floodplain — country rock junction, but others project onto the floodplain of the main stream e.g. Nos 6 and 8. There is one, No. 38, that lies partly in a tributary valley and partly between the levee and the scarp defining the edge of the flood plain (Fig. 1). Finally in this continuum, there are a few that lie almost entirely within the alluvium of the floodplain and are dammed by the natural levee of the main stream — embankment lakes of Blake and Ollier (1971).

Alluvium is often deposited in the form of an obvious levee, as it is at Nos 9 and 11 (Kaludah Lagoon), but in many cases the levee is complex, wide and of low uneven slope e.g. along the Hunter River between Nos 19 and 26 (Fig. 5). Reverse delta formation is apparent in some lagoons e.g. No. 4 ('Birds') (Fig. 3a) and in these the deepest point is well away from the dam. In others no such fan of alluvium is present so that the dam front is relatively steep and the deepest part is consequently near the dam e.g. No. 21 ('Murphys') (Fig. 3b).

Lagoon size is correlated significantly with catchment size ($r = 0.7305$, $n = 42$, $P > 0.001$), though catchments >600ha rarely contain lagoons and those below 75ha are

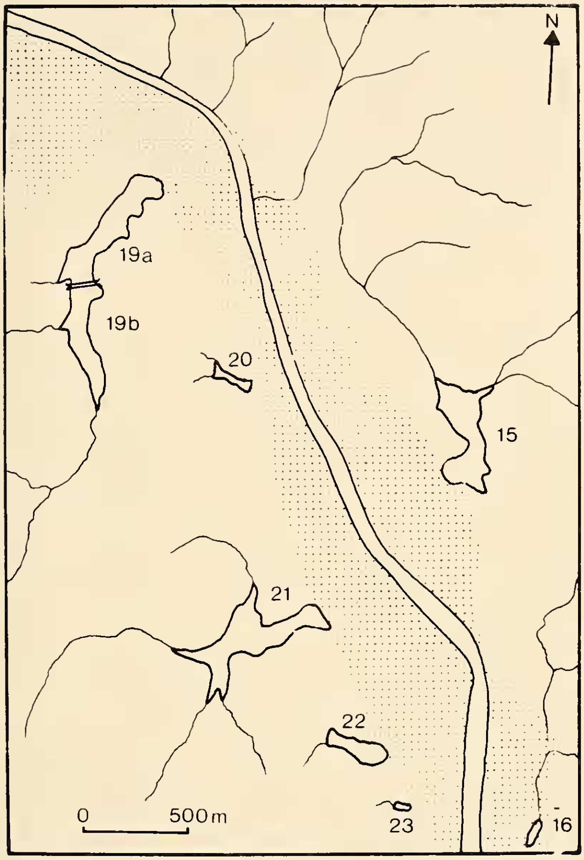

Fig. 5. Position of Lagoons 15-16 and 19-23 with reference to levee alluvium (stippled) of the Hunter River.

less likely too (Fig. 2**b**). This is probably because large catchments generate sufficient run-off to keep the channel to the main river open and very small catchments do not generate enough water to pond or more likely any depression is easily infilled with sediment from the main river.

The geomorphology of the tributary valley substantially influences the depth, shape and size of any lagoon in it. Lagoons in wide shallow valleys are typically shallow, large and with low S.D. values (e.g. Nos 11, 21, and 26), whereas those in narrow steep-sided valleys are usually smaller, deeper and more dendritic (e.g. Nos 19 and 38). The contrast in the two extremes is seen in the one lagoon, No. 4, 'Birds', where the deep northeast arm is in a steep-sided gully while the shallower southeast arm is surrounded by more gentle terrain.

Lagoons usually fill from local run-off following heavy rain, but rarely flood waters from the main stream contribute also. Following such filling, water levels are probably controlled largely by surface evaporation and by exchange with the regional watertable. However, given the great salinity increase as some lagoons dry (see later), perhaps some lagoons are at least partly perched. Although shallower lagoons are the ones most likely to be ephemeral, sediment types and geomorphic setting are also important. Lagoons largely on alluvium of sandy silt are less permanent than those in tributary valleys cut in rock and abutting alluvium.

Major floods may change the alluvial dam and hence the geomorphic and hydrologic features of a lagoon. An example is No. 19 which before the 1955 Flood was a marsh, but with the deposition of 5 to 10m of alluvium on the levee (telephone poles were almost buried) it became a permanent lagoon. Similar episodic changes to floodplain lakes on the Macdonald River near Sydney have been reported by Erskine (1986) and Henry (1977). Artificial drains silt after floods and many landowners redig their drains every few years.

(b) PHYSICOCHEMICAL ENVIRONMENT

Probably the most significant aspect of the physicochemical environment in these lagoons is its variability. Basic to this is the variable hydrologic regime as determined by their geomorphic position. The mean annual fluctuation in TDS of 177% is higher than for most freshwaters in southeast Australia (Bayly and Williams, 1966; Williams, 1967), but is nevertheless typical of small lentic waters such as billabongs of the Murray River around Albury (Shiel, 1980) and farm dams, including those nearby (Timms, 1970b; 1980). In common with these environments, but in contrast to larger reservoirs and lakes (Bayly and Williams, 1973; Powling, 1980; Timms, 1976) there are also great variations in pH, turbidity and nutrient levels. Such variations are influenced more by irregular inflows from the catchment than by within-lake processes and are exacerbated by the shallowness of the lagoons.

Other physicochemical characteristics of these lagoons indicate features typical of Australian freshwaters either countrywide or regionally, or of small shallow lentic waters such as river billabongs and farm dams. These include:

(a) TDS content in all is higher than usual for the region where only 12% of waters exceed 225mg l^{-1} (Timms, 1970c). This is probably due to their closed hydrologic regime for most of the time. Certainly, flushing after heavy local rain reduces TDS levels (Fig. 4) and this happens on average for a few days in wet years. The influence of rare river floods is unknown, but presumably flushing occurs then also.

(b) Ionic composition is typical of Australian waters as a whole (Bayly and Williams, 1973), though HCO_3 levels are relatively high, as is generally the case in northeastern NSW (Timms, 1970c).

(c) pH is generally between 7 and 8 which is usual for most freshwaters in eastern Australia (Bayly and Williams, 1973).

(d) Annual temperature range of surface waters is *c.* 15-20°C which is similar to that reported for other small sites in lowland southern Australia (Shiel, 1980; Timms, 1970b). Minima of 11-12°C are characteristic of low-altitude waters at this latitude (33° S) (Shiel, 1980; Timms, 1970b). The perceived lack of persistent stratification distinguishes these lagoons from many farm dams (Timms, 1980), typical larger reservoirs and lakes (Powling, 1980; Timms, 1976) but not from billabongs (Shiel, 1980). Any stratification in these lagoons is short-lived because of their shallowness and exposure to winds. However, more detailed studies are needed as there are some indications that at least one stratifies for weeks at a time, and given its eutrophic status, extensive deoxygenation could occur.

(e) In common with farm dams (Timms, 1980) and most inland waterbodies (Bayly and Williams, 1973) the waters of these lagoons are turbid. Consequently Secchi disc depths of <1m, often <0.5m are characteristic.

(f) Nutrient levels, particularly phosphate, are higher, than for most freshwaters in Australia (Bayly and Williams, 1973) but similar to values recorded in farm dams (Timms, 1980). As discussed earlier at least some of these nutrients are anthropogenically derived. Despite these high nutrient levels there is no evidence that the lagoons are hypereutrophic; indeed some appear at most to be mesotrophic based on evidence on their planktonic and benthic standing crops (author, in preparation). It seems high turbidity and associated limited light penetration limit production (Williams and Wan, 1972).

In summary then, while the physicochemical environment in these lagoons is typical for Australia, it is distinctive by virtue of its elevated TDS content, high turbidity and nutrient levels. Most charcteristic of all though is the high variability in all parameters.

(c) INFLUENCE OF MAN

Not one of the lagoons is unaffected by man. Indirectly, they are probably being flushed less frequently because of the flood mitigation effect of Glenbawn Dam upstream on the Hunter R. (Erskine, 1985). More directly, most landowners consider the lagoons occupy valuable grazing land, so they endeavour to drain them. Two-thirds of the lagoons are affected in this way (Table 1) with the most drastic changes being seen on the larger lagoons in wide shallow valleys. Other less obvious changes are wrought by (i) cattle wading which increases turbidity in smaller lagoons and in larger lagoons during low water periods and (ii) by use of fertilizers on upstream catchments.

Nutrient levels are probably elevated in all lagoons, particularly in those with discrete sources, e.g. duck pens. The effects of these changes on their ecosystems are unknown. Nevertheless, while some eutrophication may have enhanced waterfowl habitat in many lagoons, their natural value as drought refuges has been further reduced by drainage. Fortunately, should the opinions of landowners change, the river can right wrongs by depositing new alluvial dams or silting drains, so tributary valleys can once more be effectively dammed to become permanent lagoons again.

ACKNOWLEDGEMENT

I wish to thank many of my geomorphology students for help in mapping the lagoons, and in particular Glen King and the late Edu Nerinckx for assisting in the initial survey and interviews as well. I am grateful to numerous landowners who allowed access to their lagoons and spent time talking with us, and to the Director of the Bureau of Meteorology for supplying rainfall data for Singleton. Dr I. A. E. Bayly of Monash University and Wayne Erskine of University of N.S.W. are thanked for reviewing the manuscript.

References

ANON., 1975. — *Standard Methods for the Examination of Water and Wastewater* 14th Edit. Washington: APHA.

BAYLY, I. A. E., and WILLIAMS, W. D., 1966. — Chemical and biological studies on some saline lakes in south-east Australia. *Aust. J. Mar. Freshwat. Res.* 17: 177-228.

——, and ——, 1973. — *Inland Waters and their Ecology.* Melbourne: Longmans.

BLAKE, D. H., and OLLIER, C. D., 1971. — Alluvial plains of the Fly River, Papua. *Z. Geomorph.* N.F. Suppl. Bd. 12: 1-17.

COWARDIN, L. M., CARTER, V., GOLET, F. C., *Classification of Wetlands and Deepwater Habitats of the United States.* Washington: U.S. Fish and Wildlife Service, Office of Biological Services.

ERSKINE, W. D., 1985. — Downstream geomorphic impacts of large dams: the case of Glenbawn Dam, NSW. *Applied Geogr.* 5: 195-210.

——, 1986. — River metamorphosis and environmental change in the Macdonald Valley, New South Wales, since 1949. *Aust. Geogr. Stud.* 24: 88-107.

HAKANSON, L., 1981. — *A Manual of Lake Morphometry*. Berlin: Springer-Verlag.

HENRY, H. M., 1977. — Catastrophic channel changes in the Macdonald valley, New South Wales, 1949-1955. *J. Proc. Roy. Soc. N.S.W.* 110: 1-16.

HUTCHINSON, G. E., 1957. — *A Treatise of Limnology*. Vol. I. New York: John Wiley and Sons.

POWLING, I. J., 1980. — Limnological features of some Victorian reservoirs. *In:* WILLIAMS, W. D., (ed.), *An ecological basis for water resource management*. Canberra: ANU Press.

RILEY, S. J., WARNER, R. F., and ERSKINE, W., 1984. — *Classification of Waterbodies in New South Wales*. North Sydney: N.S.W. Water Resources Commission.

SHIEL, R. J., 1980. — Billabongs of the Murray-Darling System. *In:* WILLIAMS, W. D., (ed.), *An ecological basis for water resource management*. Canberra: ANU Press.

TILZEY, R. D. J., 1980. — Introduced Fish. *In:* WILLIAMS, W. D., (ed.), *An ecological basis for water resource management*. Canberra: ANU Press.

TIMMS, B. V., 1970a. — Variations in the water chemistry of four small lentic localities in the Hunter Valley, New South Wales, Australia. *Aust. Soc. Limnol. Bull.* 3: 36-9.

——, 1970b. — Aspects of the limnology of five small reservoirs in New South Wales. *Proc. Linn. Soc. N.S.W.* 95: 46-59.

——, 1970c. — Chemical and zooplankton studies on lentic habitats of north-eastern New South Wales. *Aust. J. Mar. Freshwat. Res.* 21: 11-33.

——, 1976. — A comparative study of the limnology of three maar lakes in Western Victoria. I. Physiography and physiochemical features. *Aust. J. Mar. Freshwat. Res.* 27: 35-60.

——, 1980. — Farm Dams. *In:* WILLIAMS, W. D., (ed.), *An ecological basis for water resource management*. Canberra: ANU Press.

WILLIAMS, W. D., 1967. — The chemical characterisation of lentic surface waters: a review. *In:* WEATHERLEY, A. H., (ed.), *Studies on Australian Inland Waters and their Fauna*. Canberra: ANU Press.

——, and WAN, H. F., 1972. — Some distinctive features of Australian inland waters. *Wat. Res.* 6: 829-36.